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ABSTRACT

Thus far the several different strategies that have been employed to investigate the size of the perceptual span during reading have not yet resolved the question of whether good readers have a larger span than poor readers. An investigation was designed to determine the region of text from which letter information is used during a fixation of the eyes. Eight good readers and eight poor readers from the fifth grade participated in the study. A computer based laboratory system was used for displaying the texts to be read and for monitoring and recording the eye movement patterns of the subjects engaged in reading. Results indicated that both groups acquired letter information from a region of text extending from two letters to the left of the center of fixation to about six letters to the right. The average reading rate of the poor readers was about 70% of that for the good readers, while durations of fixations made by poor readers in the control condition were approximately 30% longer than the fixation durations of the good readers. Finally, the average lengths of saccades of the poor readers was about 25% shorter than those made by the good readers. There was no evidence to suggest that skilled readers utilized letter information from a wider region of text than did less able readers. (HOD)

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CENTER FOR THE STUDY OF READING

Technical Report No. 251

THE SPAN OF LETTER RECOGNITION OF GOOD AND POOR READERS

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Abstract

A computer-controlled eye movement contingent display paradigm was used to investigate the span of letter recognition for good and poor readers during a reading task. The results of the study indicate that both groups acquire letter information from a region of text extending from 2 letters to the left of the center of fixation through to about 6 letters to the right. There was no evidence to suggest that skilled readers utilize letter information from a wider region of text than do less able readers. The findings have significant implications for theories of information processing and theories of guidance of eye movements. The strength of the results lie in the fact that the present investigation is the first study to compare the performance of good and poor readers when peripheral information is disrupted but foveal information remains intact.

The Span of Letter Recognition of Good and Poor Readers

Gibson (1965) has suggested that the ability to respond to larger and larger amounts of graphic visual information underlies increased reading skill. That is, older children as compared with younger children, or better readers as compared with poorer readers of the same age, are able to extract information from a greater region during a fixation of the eyes. Smith (1971) has claimed that what distinguishes the fluent from the less-skilled reader is the number of letters or words that can be identified in a single fixation.

The notion that the size of the perceptual span increases as a function of reading ability has many advocates among researchers seeking to explain the differences between skilled and less skilled readers (Gibson, & Levin, 1975; Haber, 1978; Harris, 1941; Patberg, & Yonas, 1978). Given the assumption that such an increase occurs, the reading theorist is then concerned with trying to account for how the skilled reader is able to acquire more information during a fixation than is his less able counterpart (LaBerge, & Samuels, 1974).

The several different strategies which have been employed to investigate the size of the perceptual span during reading will be briefly reviewed. In discussing the limitations of each of the approaches, it will be shown that the question of whether good readers have a larger perceptual span than poor readers has not yet been resolved. One approach

which has been used to study this issue has been simply to divide a given number of words by the number of fixations made while reading those words (Harris, 1941; Spragins, Lefton, & Fisher, 1976; Taylor, Frackenpohl, & Pettee, Note 1). The findings from studies that have used this technique have been remarkably consistent over the years. Beginning readers average about .5 words per fixation and adult readers about 1.5 words. However, as McConkie and Rayner (1976a) point out, this method of estimating the perceptual span is based on the assumption that on successive fixations the perceptual spans do not overlap or that they overlap the same amount.

If this assumption is incorrect, such estimates of the span of recognition are not accurate. This is particularly likely to be a problem when fixations following regressive eye movements are included in the number of fixations. These are probably fixations of words seen earlier, thus not indications of new words being seen. In the Spragins, Lefton, and Fisher (1976) study, it appears that the total number of fixations included fixations following regressive saccades. Since it was found that children made 10% more regressions than adult readers, their results are probably confounded by this difference.

A second approach to the question attempts to establish how much information can be obtained during a single fixation by simulating a fixation through a tachistoscopic presentation. Typically, a string of random letters, words, or phrases is presented for exposure times of up to 250 msec, which is the average length of the duration of a fixation.

Using this technique, Marcel (1974) found that good readers were able to report more information than poor readers, as a function of contextual constraint. Research by Sperling (1960) has raised questions about whether this technique can be taken to indicate what information is actually being seen during a fixation. He demonstrated that subjects were seeing much more in a tachistoscopic display than they could report afterwards. Apparently, much of the information was being seen and was available for selection immediately following the presentation, but a relatively small amount could be encoded in a form which supported oral report. If encoding and memory provide a bottleneck to these reports, it seems likely that this would be true with children of different reading abilities (Lunzer, Dolan, & Wilkinson, 1976; Naidoo, 1972). Thus, the fact that poorer readers report less from such presentations may reflect their ability to encode and report, rather than indicate a difference in what they see.

As a third approach, some researchers have used the eye-voice span (EVS) technique to determine the span of perception in reading (Buswell, 1920). The EVS is a measure of the amount of material or time that the eye is ahead of the voice in oral reading. It may be measured either by recording eye movements and vocalizations at the same time during reading or by suddenly making the text unavailable and requiring the subjects to continue their vocalizing of the text as far as possible. It has been found that good readers have a longer EVS than poor readers (Morton, 1964). On the basis of this evidence, Levin and Kaplan (1970) argue that

the good reader actually sees more in a fixation. Marcel (1974) rejects this claim for two reasons: First, the EVS for text is between 640 and 700 msec. Since fixations only last about 250 msec, the EVS is probably the result of at least two fixations. And second, since the EVS is measured during continuous oral reading, it may well reflect output restrictions rather than perceptual processing.

A fourth approach is to determine how far from the center of vision letters and words can be identified when presented individually (Bouma, 1973). Using this technique, Bouma and Legein (1977) found that the functional visual field appears to be narrower for poor readers than for good readers. McKeever and Huling (1970), however, found no difference between good and poor seventh-grade readers in identification of peripherally presented words.

Studies of this sort have typically shown an asymmetry in the visual field, with words and letters being identified by readers further to the right than to the left (Bouma, & Legein, 1977; Bouma, 1973; McKeever, & Huling, 1970. Fisher and Lefton (1976) also report a right-field advantage in a developmental study using a recognition task. The research of McConkie and Rayner (1976b) indicates that adults show an even greater asymmetry during reading. They found that during a fixation relatively skilled readers do not use visual information more than 4 letter positions (1 degree of visual angle) to the left of the center of the fixation, though they do use visual information considerably farther than that to

the right (McConkie, & Rayner, 1976b; Rayner, 1975). More recently, Underwood (1980) found that adult readers were not using letter information more than two character positions to the left of the fixation point.

Another phenomenon found in studies of this type is that a single letter may be identified more easily in the periphery than an embedded letter (Chastain, & Lawson, 1979; Mackworth, 1965). It appears that surrounding letters have a masking effect on the target stimulus, thus reducing the effective span of recognition. The region within which letters can be identified is apparently not a constant, but varies with the nature of the stimulus configuration.

In a related study by Jackson and McClelland (1975), fast and slow adult readers were required to identify two different letters presented simultaneously to the left and right visual fields. Jackson and McClelland found that the breadth of visual field from which subjects could identify two such disparate stimuli was approximately the same for the fast and slow readers.

In attempting to generalize the results from these studies, two problems arise. First, it is not clear that the reader utilizes the full region of visual information which is potentially available during a fixation. Thus, while these studies may give some indication of the region within which words and letters can be identified if desired, they provide no information about whether this full region is actually used

during a fixation in reading. The second problem results from the fact that language constraints can facilitate the identification of words (Morton, 1964; Tulving, & Gold, 1963; Zola, 1981). Thus, the data from these studies may underestimate the region of text within which identification might occur when language constraints were operating.

A fifth strategy developed to investigate whether the skilled reader acquires information from a wider visual field than does the less skilled reader relies upon the visual disruption of the text. Such visual disruption may be achieved in several ways: by omitting spaces between words, by filling the spaces with a character, by geometrically transforming the text, or by presenting the text in alternating upper- and lower case letters. The rationale behind this approach is that skilled readers will be more affected by the disruptions than less skilled readers because they rely more on the use of peripheral information than do less skilled readers. Fisher and Lefton and their colleagues have used this technique extensively (Fisher, Lefton, & Moss, 1978; Fisher, & Montanary, 1977; Lefton, & Fisher, 1976; Spragins, Lefton, & Fisher, 1976). The results of these studies have consistently supported the rationale.

Text disruption studies of this type, however, do not directly address the question of the size of the perceptual span. Rather, they attempt to indicate how the peripheral information is used in the reading situation. One criticism that may be made of the studies is that not only is the information in the visual periphery disrupted, but also the

information in the foveal region. Thus, it is not clear that the effects are strictly due to peripheral vision. A second point that needs to be made is, of course, that these studies have typically not involved subjects in a normal reading task.

The final strategy to be discussed here involves restricting the visual field artificially to the region around the fovea and obtaining the maximum visual field beyond which no further gain is observable for the reading task (Newman, 1966; Poulton, 1962). In these studies it was found that the error rate in oral reading was a function of the size of the visual field. Recent studies have eliminated peripheral information by illuminating a region of text contingent upon the position of the eyes (Ahlen, 1974; Ikeda, & Saida, 1978). The span of perception was determined by establishing the size of the window at the point when eye movements were disrupted.

Patberg and Yonas (1978) and Patberg (Note 2) used a simplified version of this principle i.e., eliminating the peripheral information in a developmental study. Again, the hypothesis was that the better reader would be more affected by the loss of peripheral information than the poorer reader. The results of their studies supported their hypothesis. However, the nature of the printed text precluded the reader from acquiring any information about the words beyond the one being fixated. In a normal reading situation when a reader is either fixating short one- to three-letter words, or the final letters of longer words, visual

information from the adjacent word is within the foveal region of the eye. It is not known how much the elimination of this information confounded the results of their studies.

McConkie and Rayner (1975) using a computer system which made it possible to investigate what aspects of the textual display are acquired at different distances from central vision, had subjects read text displayed on a cathode ray tube (CRT) as their eye movements were being monitored. On each fixation, all letters a particular distance to the left and right of the letter at the center of vision were replaced with other letters (for instance, with X's or with letters visually confusable with the original letters). This produced a "window" of normal text at the area where the eye was centered, so the reader was able to read in this region. Outside this region, in the parafoveal and peripheral visual areas, the original text was replaced with letter strings having specific relations to the original text. The arrangement permitted the experimental manipulation of two variables: the size of the window (how wide a region of normal text lay at the location where the reader was directly looking during that fixation) and the nature of the visual pattern outside the window (what visual characteristics of the original text were present or altered in the peripheral visual areas). The studies attempted to identify how far out into the periphery various types of visual information (specific letters, word shape, and word length patterns) were acquired during a fixation by determining how small the visual window could be made, without causing a deterioration in reading

performance, when various characteristics of the original text were maintained in peripheral vision. The study was successful to some degree and still stands as one of the best sources of evidence available concerning the size of the perceptual span in reading.

The purpose of the present study is to investigate one aspect of the perceptual span of good and poor readers using a modified version of the experimental paradigm developed by McConkie and Rayner (1975), as just described. That is, the investigation is designed to determine the region of text from which letter information is used during a fixation of the eyes. This region will be referred to as the span of letter recognition. Thus, it should be noted that other forms of visual information that may be part of the perceptual span, such as word length or word shape, will not be studied here.

Method

Subjects

Eight good readers and eight poor readers from Grade 5 participated in the study. The criteria for selection of the children were:

1. All children spoke English as their native language.
2. All children had normal, uncorrected vision.
3. All children were of at least average intelligence. Children with an IQ of less than 90 were not included in the study.

4. Children selected as good readers were reading at, or above, their expected grade reading level, i.e., grade 5.5 or higher.

5. Children selected as poor readers were reading at least 12 months below grade level, i.e., grade 4.5 or below.

Details of age, sex, and reading ability of the subjects are provided in Table 1.

Insert Table 1 about here.

Materials

Twenty-four individual texts were prepared for this research. Seven passages, each 20 lines in length and rated at the fourth-grade readability level, were used as practice materials. Seventeen passages of expository text were adapted from the SRA Reading Laboratory (Parker, 1958) for use as experimental materials. According to the Fry Readability Formula (Fry, 1972) all experimental passages were at the third grade reading level. This level of difficulty was selected so that the poor fifth-grade readers would have little trouble with the reading. Each passage was 10 lines in length, with up to 70 characters per line. The experimental conditions were implemented during the reading of 15 of these passages; the other two were used as warm-up passages.

Equipment

A computer-based laboratory system was used for displaying the texts to be read and for monitoring and recording the eye movement patterns of the subjects engaged in reading. This laboratory facility is centered around a Digital Equipment Corporation (DEC) PDP 11/40 computer with a laboratory peripheral system and a DEC VT-11 graphics display system. The text was displayed one line at a time with upper- and lowercase characters produced by the VT-11's a hardware character generator. This particular CRT (cathode-ray tube) uses a P-31 phosphor, which decays to 1% of the original intensity in 500 microsec. Pressing a button called the next line of text onto the CRT, permitting subjects to read multiline passages without difficulty. The CRT was 48 cm from the subjects' eyes, with three letter positions subtending one degree of visual angle. Eye movements were monitored using a modified Biometrics Model SC limbus reflection eye movement monitor (Young, & Sheena, 1975). The computer sampled the horizontal component of the eye position signal every millisecond, and was programmed to produce changes in the line of text contingent on aspects of the reader's eye movement pattern. A more complete description of this system can be found in McConkie, Zola, Wolverton, and Burns (1978).

Procedure

Experimental manipulations. On selected fixations during reading, letters in certain regions of the display, defined with respect to the center point of the reader's fixation, were replaced by other letters,

thus providing erroneous text in specific retinal regions. These are referred to as regions of replaced letters. In these regions, each letter was replaced by its most visually dissimilar letter from the same set, where letters were grouped into three sets: ascenders, descenders, and those which neither ascend above the others nor descend below the line. Visual similarity was determined from response latency data in a task in which subjects judged whether pairs of letters were the same or different. Thus, replacement letters were as different from the original letters as possible within the limitations of the set of English letters, without changing the external shape of the word. A region of replaced letters was determined by defining a boundary with respect to the reader's point of fixation. This boundary could lie a given number of letter positions to the left, or right, of the point of fixation. All letters to the left of the left boundary, or right of the right boundary, were then replaced with other letters, thus producing a letter string in that region which typically contained no English words and typically violated rules of English orthography, but which did preserve more gross visual characteristics of the original text such as external word shape, word length, and punctuation.

In this study, four letter replacement conditions were used, in addition to a control condition: left-2 (all letters more than two to the left of the fixated letter were replaced), right-3 (all letters more than three to the right of the fixated letter were replaced), right-5, and right-7.

The actual replacement occurred very early in the fixation, as soon as the forward progress of the saccadic movement was completed (that is, as soon as no further progress of the saccadic movement was detected in a 3 msec period). Since the eye movement signal lags 3 msec behind the eye's actual behavior, since the criterion involved a 3 msec delay, and since the CRT requires 3 msec for a line of text to be changed, the actual change was completed within the first 10 msec of the fixation. As soon as movement of the eyes was detected of sufficient magnitude as to indicate that a saccadic movement was once again under way, the modified line of text was returned to the original. Thus, the letter replacement, when it occurred, lasted for a single fixation.

The experimental manipulations were not made during the reading of the first or last lines of the passage. On the remaining 8 lines, four of the five conditions were scheduled to occur on each line. The changes were scheduled to occur on the fixations following the second, fourth, sixth, and eighth forward saccades in a counterbalanced order. Of course, whether all four conditions actually occurred depended on whether the subject made 8 forward saccades on the line. No changes were implemented following regressive saccadic movements of the eyes.

Illustrated in Figure 1 is a line of text as it may have been displayed on successive fixations to a subject. Assuming Fix 1 follows the first forward saccade made by the child as he read the line, the first experimental condition occurred on Fix 2. On this fixation condition

right-3 was implemented; i.e., all letters further than three character positions to the right of the fixation point were replaced by other letters. As the next saccadic movement was initiated, the normal line of text was restored to the CRT screen. No experimental manipulation occurred on the next fixation. On Fix 4, condition left-2 was implemented i.e., all letters further than two character positions to the left of the fixation point were replaced by other letters. The next change occurred on Fix 6, when condition right-7 was implemented. On Fix 8, condition right-5 occurred. The control condition was not scheduled for this line for this subject and so is not shown in Figure 1.

Insert Figure 1 about here.

Design

Five conditions were used in this study: the four experimental conditions described above (left-2, right-3, right-5 and right-7) and a control condition in which the computer algorithm carried out text replacement as in the other conditions, except that letters were replaced by themselves, resulting in no perceptible change on the CRT. The procedure guaranteed that fixations in the control condition were selected in the same manner as those in the experimental conditions.

The presentation of the five conditions was counterbalanced over 15 passages, with changes taking place on eight lines of each passage. Thus, the maximum number of data points that could be collected per condition for each subject was 96. It was anticipated that there would be approximately a 30% loss of data because of head movement, eye blinks, and failure to make sufficient forward saccades on some lines.

Half the subjects in both ability groups read the passages in order 1 through 15. The remaining subjects read passages 8 through 15, then 1 through 7. Two additional passages were included for warmup purposes; no experimental manipulations were made in these passages.

Experimental sessions. When the child arrived, some time was spent explaining about the laboratory. Then the subject was seated in front of the display unit and was physically positioned in a manner conducive to head stability. A bite bar and headrest helped to minimize movement. After a brief, initial calibration of the eye position monitoring equipment, the experimental procedure was explained.

The first session was a screening and practice session. To become acquainted with the button pressing procedure, the child first read a passage of text presented on the CRT without the encumbrances of the eye movement monitoring procedures. The child then read a second passage during which eye movements were being recorded and during which head stability was emphasized. It was not until after reading the third passage that the child was asked questions about what had been read in

order to assess comprehension of the material. Those children who were able to function in the experimental situation read four more passages. During the reading of the additional passages, the window manipulation was presented on the second and fourth fixations of each line. All of the data collected during this hour-long session were discarded.

In all, 31 children participated in the first session. Of these, 16 were invited to return for a second session. Those children who were unable to remain relatively still during the reading, who were difficult to calibrate, or who blinked excessively did not participate further.

At the beginning of the second session, the reading procedure was reviewed with the child. During this session, each subject read two warm-up passages and all fifteen of the experimental passages. After each passage, the experimenter asked the child two or three questions about information contained in the passage just read. The oral questioning technique was selected for three reasons. First, the subject did not have to be moved away from the eye tracking equipment as would be required to provide written responses. Thus, recalibration of the subject was quickly and easily achieved before each passage. Second, the oral testing strategy reduced the likelihood that the child, particularly the poor reader, would feel threatened by the situation. Third, the oral questioning procedure took less time to administer than did a written questionnaire approach.

Each subject remained in the experimental situation until the reading of the first seven experimental passages had been completed or until the child requested a rest period. After a 5-minute interval, the child read the remaining eight passages. The entire session took approximately 1 hour and 15 minutes.

Results

Figure 2 illustrates the pattern of the eye movements which were analyzed in this study. The saccadic movement of the eyes immediately prior to the fixation during which an experimental condition was implemented is designated as S0. Any fixation in which there occurs an experimental manipulation is referred to as F0. The saccade immediately following F0 is S1. Likewise, the next fixation is termed F1. Thus, no letter replacement occurred during fixations labelled F1; any effects found on these fixations can only be due to manipulations occurring on the prior fixation.

Insert Figure 2 about here.

Occasionally very short saccades were made after the initial display change which were of small enough magnitude that the computer was unable to determine reliably, on line, that a saccade was in progress. In these cases, the line of text was not changed back to normal until the next

saccade. Such fixations were marked in the data and excluded from data analysis. Also, blinks and other eye lid movements occasionally resulted in the stimulation of a text change during a fixation; fixations of this sort were also eliminated from the analysis. Thus, the only fixations included in the data analysis were those on which the display changes occurred at the appropriate times.

Several differences between the good and poor readers, which are discussed in more detail below, have been consistently demonstrated in previous studies. Good readers were found to have shorter fixation durations and longer saccades than poor readers. Good readers read at a rate of 182 words per minute, compared with 130 words per minute for poor readers. The rate of reading by the children in this experiment was comparable to that found in other studies (Spragins, Lefton, & Fisher, 1976; Taylor, 1965). This may be taken as an indication that the children were not adversely affected by the experimental situation.

A three-factor ANOVA was used to analyze the data. The factors were Condition (five conditions), Reading Ability (good readers vs. poor readers), and Subject (8 subjects nested in each ability level). Distributions of eye movement measures tended to be highly skewed, with occasional fixations over 500 msec and occasional saccades over 20 letter positions. These extreme values can unduly influence the values of means. Therefore, data analyses were carried out by calculating medians for each subject on each of the variables of interest, for each condition, and then

entering these medians into the ANOVA's.

Duration of Fixation F0

The 2 x 5 x 8 ANOVA on the F0 fixation duration data yielded a significant main effect for reading ability, F (1,14) = 4.77, $p < .05$. The average fixation duration (mean of the individual subjects' medians) for good readers was 196 msec as compared with 234 msec for poor readers, a difference of 38 msec. There was no significant main effect for condition, F (4,56) = 0.25, $p > .05$. The interaction effect between reading ability and conditions was not significant, F (4,56) = 0.59, $p > .05$.

There is no pattern in the data for either group to suggest that the experimental manipulations systematically influenced the duration of F0. No condition differed from its appropriate control condition by more than 10 msec.

Insert Figure 3 about here.

Length of Saccade S1

For the length of S1 forward saccades, the main effect for reading ability was found to be significant, F (1,14) = 5.94, $p < .05$. Again, there was no significant main effect for condition, F (4,56) = 0.59, $p >$

.05. The interaction effect between reading ability and condition was not significant either, F (4,56) = 0.10, p > .05. Figure 4 shows that the average length of the forward S1 saccades for the good readers is consistently at least one character position, or nearly 20% longer, than that for the poor readers.

Although the differences in forward saccadic length at the different boundary locations were not statistically significant, there is some pattern in the data for both groups. The average length of the saccades when the letters to the left were replaced (i.e., the left-2 condition) was shorter than the control condition. Similarly, on the right, the further from the fixation point the letter replacement occurred, the longer was the mean length of the saccades. However, the differences were very small. No condition differed from its appropriate control group by more than 0.3 character positions.

Insert Figure 4 about here.

Duration of Fixation F1

The ANOVA yielded a significant main effect for condition on F1 fixation duration, F (4,56) = 5.58, p < .01, in contrast to the results of the previous two dependent variables. However, there was no significant main effect for reading ability, F (1,14) = 2.49, p > .05. Again, there

was no significant interaction effect between reading ability and condition, F (4,56) = 0.40, p > .05.

A Newman-Keuls test of the significance of the pairwise differences between the means for each difference was conducted (Kirk, 1968). Three of the conditions, left-2, right-3 and right-5, differed significantly from the control condition, p > .05. The difference between right-7 and the control condition was not statistically significant. Thus, the three experimental conditions closest to the center of fixation significantly inflated the duration of fixation F1, but the right-7 condition did not. This indicates that subjects used letter information at least as far as 2 letters to the left of the center of the fixation and up to 7 letters to right.

Insert Figure 5 about here.

The Effects of Boundary Location with Respect to Words

An analysis of the data was carried out for the left-2 condition to compare the effects of the letter replacement boundary occurring within the fixated word with the boundary occurring to the left of that word. The notion being investigated here is that if words act as some sort of perceptual unit, then the disruptive effects of the letter replacement should be greater when the boundary occurs within the fixated word (i.e.,

errors occur in the word on which the eyes are centered) than when the boundary is located before the word (i.e., erroneous letters occur only in words to the left of the fixated word). It is therefore hypothesized that the duration of fixation F1 will be longer in the within-word condition than in the adjacent-word condition.

The several possible alternative conditions that may have occurred within this dichotomy of the data are illustrated in Figure 6. The center of the fixated region of text is indicated by the arrow. It can be seen that under condition left-2 the letter replacement boundary could occur within the fixated word only if that word was at least 4 letters long. If the fixated word was less than 4 letters in length, or if the subject fixated in the first 3 letter positions of the word, only words to the left of the fixated word would contain errors. It was possible, as in line 3 of Figure 6, for a single-letter word to the left of the fixated word to be free of errors, but in most cases the word to the left had part of its letters (Figure 6, line 4), or all of its letters (Figure 6, line 5) replaced. These different possible conditions were not distinguished in the analysis to be reported here. Similar instances were also identified in the control condition data: These were instances in which the errors would have occurred at these locations had they been in the experimental conditions.

Insert Figure 6 about here.

Only those F1 fixations which were preceded by forward saccades were included in the data analysis. The number of data points in the different conditions, on which the group medians were based, ranged from 40 for the good readers left-2 within-word condition, to 203 data points for the poor readers control-adjacent-word condition. Thus, although there were sufficient data to provide relatively stable group medians, there were not enough data points in all conditions to permit a more fine-grained analysis.

Figure 7 illustrates the values for the different conditions. It appears that any inflation of fixation F1 in the left-2 condition may be attributed to those occasions when the location of the letter replacement boundary occurred to the left of the fixated word. For both groups of readers, the data values for the left-2 and control conditions are almost identical when the boundary is located within the fixated word. This is entirely contradictory to the hypothesis being tested. That is, it was expected that the effects would be greater if the fixated word was disrupted than if only words immediately to the left were disrupted. Thus, there is no empirical support for the notion that words were functioning as perceptual units for either good or poor readers. It should be noted that the length of fixation durations for the control

condition were greater in the within-word condition than in the adjacent-word condition for both good and poor readers.

Insert Figure 7 about here.

Summary of Results

Several general observations can be drawn from the analyses of the data obtained from this experiment on the perceptual span of children.

1. The mean fixation duration of good readers was consistently shorter than that for poor readers across all conditions for F0 and F1, although the difference was not statistically significant for F1.

2. The mean saccade length of the good readers was approximately a character position longer than that of the poor readers across all conditions for S1.

3. The only statistically significant effects resulting from the experimental manipulations were found on fixation F1. No statistically significant effects were manifested on fixation F0, the fixation on which errors were present, or on the immediately following forward saccade S1.

4. The evidence does not indicate any differences in the size of the span of letter recognition for the two groups of readers.

5. The effects of the boundary location with respect to word position does not support the notion of words functioning as perceptual units for either good or poor readers.

Discussion

The eye movement patterns of the good and poor readers in this experiment are generally consistent with the findings of other studies (Taylor, 1965). The average reading rate of the poor readers was about 70% of that for the good readers, as measured by the number of words read per minute. The durations of fixations made by the poor readers in the control condition were approximately 30% longer than the fixation durations of the good readers. The average lengths of saccades of the poor readers was about 25% shorter than those made by the good readers. In spite of these differences, the results indicate that the size of the span of letter recognition is much the same for both groups.

The fact that there was no evidence to support the hypothesis that good readers have a wider letter recognition span than poor readers is somewhat surprising. It appears that there is no difference in the size of the region from which good readers and poor readers obtain letter information during a fixation. That is, there were no significant interaction effects between reading ability and conditions on any of the three dependent variables which would indicate that good readers are more sensitive to disruption of peripheral information than are poor readers. The results indicate that both groups of children are acquiring

information from at least 3 letters to the left of the fixation point and up to approximately 6 letters to the right. It should be noted that the text used in the study would have presented less difficulty to the good readers than to the poor readers. If it was the case that the span of letter recognition is influenced by text readability (i.e., the more difficult the text, the smaller the span), then the good readers should have been even more likely to have had a wider span.

The similarity in the findings of this experiment and the results of other studies using the same paradigm but where the subjects were adults is striking (Underwood, & McConkie, Note 3). In their study, Underwood & McConkie found that adults used letter information no further than 2 letters to the left of the fixation point and up to 6 letters to the right. Thus, the evidence suggests that not only is the span of letter recognition similar for both good and poor readers, but also there is no increase in the size of the span when these readers are compared with college students.

The evidence that has been put forward previously to support the hypothesis that the span of letter recognition increases as a function of reading ability needs to be closely examined. Patberg and Yonas (1978) conducted a study in which good and poor readers read passages of normal text and passages typed with 13 spaces between each adjacent pair of words. By spacing the words so widely apart, they reduced the amount of peripheral information that could be acquired from one word while the

prior word was being fixated. They found that good readers did not perform as well on the spaced condition as they did on the normal text, whereas the performance of the poor readers was unaffected by the different tasks. In their experiment, performance was defined as the number of questions answered correctly per minute of reading time. On the basis of this evidence, Patberg and Yonas concluded that as reading improves, the perceptual span increases beyond the single word.

It can be argued that there is nothing in the Patberg and Yonas study that permits any conclusions about the nature of the perceptual span as a function of reading ability. To draw such conclusions necessitates the tenuous assumption that reading efficiency, as defined by the authors, is related to the size of the perceptual span. There is no evidence to support this contention. An alternative explanation of the results is suggested by the authors themselves. They suggest that skilled reading may be disrupted to a greater degree than unskilled reading by any change in the task requiring a modification of well-practiced techniques.

Fisher and Lefton and their colleagues have conducted extensive research into eye movements of readers, including a number of developmental studies. A strategy used by these investigators is to disrupt the text in a variety of ways and examine the effects of the disruption on the eye movements of the reader. Spragins, Lefton, and Fisher (1976) examined the effects of spatial manipulation of text on adults, third, and fifth graders. Among the conditions included in the

study were the following:

1. This is a line of normal text.

2. This+is+a+line+of+filled+space+text.

3. Thisisalineofnospacedtext.

The size of the perceptual span was arrived at by dividing the number of character spaces in the paragraph by the total number of fixations made by the subject. Spragins et al. concluded that the size of the perceptual span was related to reading ability.

A possible explanation for the difference between the results of the present experiment and the Spragins et al. study lies in the fact that different sorts of information were disrupted. Spragins et al. relied upon the elimination of spatial cues to disrupt the reading process of the subjects, whereas letter information was disrupted in the present experiment. The spacing between the words and the shape of the word was maintained. It may well be that adults tend to be more reliant on spatial cues than children. However, the claim that the adult reader relies more heavily on peripheral cues than does the younger reader is not unequivocally supported by their results, since the disruption of the text occurred both foveally and peripherally.

There seem to be two possible explanations to account for the differences in the findings of the present study and the earlier

investigations. First, it may be that the experimental strategies are sufficiently different to preclude comparisons of any data; that is, different aspects of perception are being studied. Second, there are good reasons to believe that the previous experiments were not measuring perceptual span as such at all.

The generally accepted view that a critical distinction between good and poor readers is the ability of the former to utilize visual information further into the the peripheral region of the text during a fixation is not supported by the results of the present study. There is no doubt that there are many factors which contribute to the reading ability of children. For example, it has been suggested that good readers are able to guide their eyes more efficiently than poor readers (Gilbert, 1959; Lefton, 1978; Lefton, Lahey, & Stagg, 1978). Several investigators believe that poor readers may have unsystematic attentional scanning patterns (Heron, 1957; Marcel, 1974). This study, particularly when considered together with the results of Underwood and McConkie (Note 3) has eliminated one factor long believed to have had a bearing on reading performance.

Temporal Aspects of Information Processing

The question of when available information is processed is of central importance to understanding reading. The answer will have significant implications for theories of language processing and comprehension, as well as for eye movement guidance. In this experiment, neither the good

readers nor the poor readers showed effects of the experimental manipulations on the fixation during which they were implemented, nor on the following saccade. It was not until the following fixation, F1, that the effects were manifested. This suggests, of course, that the duration of a fixation may be influenced by the information acquired on a previous fixation. A similar finding has been reported by Underwood and McConkie (Note 3).

This finding poses difficulties for models of reading which assume that the duration of a fixation is determined by the time required to process the information acquired during that fixation (Just, & Carpenter, 1980). Just and Carpenter claim to have developed a model of reading comprehension that is able to account for the allocation of eye fixations. Their model proposes that gaze durations reflect the time to execute comprehension processes, for example, longer fixations manifest longer processing caused by the word's frequency and its thematic importance.

A necessary assumption of the Just and Carpenter model of reading is that the eyes remain fixated on a word as long as the word is being processed. The data yielded by the present study make it difficult to sustain such an assumption. The evidence suggests that information acquired on one fixation is still being processed after that fixation has ended (i.e., after the visual information is no longer available to the reader), or at least that the effect on the eye movement pattern is delayed until after that fixation.

Eye Movement Patterns

The present study yielded some interesting data relevant to the issue of eye movement patterns. First, it was found that while there were no differences in the size of the spans of letter recognition of good and poor readers, the average length of forward saccades of poor readers was approximately 25% less than that of good readers. This could be taken as evidence against the notion that the length of the saccade is related to the amount of information encountered during the fixation, as assumed in the analyses by Fisher and his colleagues.

Second, the duration of fixation F1 was examined according to whether it was followed by a forward or regressive saccade. From Table 2 it can be seen that the increased duration time of fixation F1 for conditions right-3 and right-5 is entirely attributable to those instances when F1 is followed by a forward saccadic movement. Thus, it appears that a relationship exists between the duration of fixations and direction of saccades. This finding has been corroborated by Underwood and McConkie (Note 3).

Insert Table 2 about here.

It is apparent that the relationship between saccadic movements and fixation durations is one of considerable complexity, and will not be easy

to explicate. However, it is clear that the claim that these two components are unrelated is not entirely true (Levy-Schoen, & O'Regan, 1979; Rayner, & McConkie, 1976).

Further Research

In one sense, the present study should be viewed as a first attempt to apply the eye movement contingent display paradigm (McConkie, & Rayner, 1975) to investigate the language processing differences between children of different reading abilities. As such, it has been shown to be a successful technique in providing information on the nature of those differences. Further research is required to corroborate the basic finding that there is no difference in the size of the perceptual spans of good and poor readers, and to more clearly define the parameters of the region from which visual information is acquired during a fixation.

The experimental technique used here should lend itself to investigating whether other types of visual information, such as word boundaries, lengths of words, or their shapes are used more effectively by good readers than by poor readers.

A developmental study of the span of letter recognition of children is an important issue to be addressed. It may be that by Grade 5 the size of the span has stabilized, but that younger children do acquire letter information from a smaller region of text during a fixation. Although it would be difficult to use this paradigm with beginning readers, because of

the experimental constraints, there is no doubt that children younger than the subjects who participated in this study could cope with the demands of the situation. The question of why the effects of the experimental manipulations were not manifested until one fixation after implementation needs further investigation. Similar studies using adults as subjects have reported more immediate effects of such manipulations; i.e., the duration of fixation F0 is increased, and the length of saccade S1 is shortened. This finding, of course, raises the complex issue of the rate of language processing during reading.

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Table 1

A Description of the Two Groups of Grade Five Readers

Good Readers				Poor Readers			
Subject	Sex	Age	Rdg (grade)	Subject	Sex	Age	Rdg (grade)
1	F	11.4	7.1	1	M	11.2	3.5
2	F	10.3	8.2	2	F	10.7	3.7
3	F	11.0	6.1	3	F	10.5	4.6
4	F	11.0	5.5	3	F	11.8	3.2
5	F	10.8	8.2	5	M	11.7	4.0
6	M	10.7	5.6	6	M	11.3	3.9
7	M	10.5	6.1	7	M	10.5	3.1
8	M	10.5	8.3	8	M	11.2	3.5
Means		10.8	6.9	Means		11.1	3.7

Table 2

Duration of Fixations (msec) F0 and F1 as a Function of the Direction of the Following Saccade for All Conditions in Experiment 2

Boundary Location	F0		F1	
	S1 Forward	S1 Regress.	S2 Forward	S2 Regress.
L0	208	273	235	192
R3	203	176	234	192
R5	200	175	225	205
Control	204	189	203	194

Figure Captions

Figure 1. An example of a line of text as it may have been displayed on successive fixations to a subject. The arrow indicates the center of fixation.

Figure 2. A schematic representation of hypothetical eye movements occurring while reading a line of text.

Figure 3. The average durations of fixations during which letters were replaced in fixation F0, as a function of the boundary location of the replaced letters.

Figure 4. The average lengths of forward saccades S1 as a function of the boundary location of replaced letters.

Figure 5. The average durations of fixations F1 following S1 forward saccades, as a function of the boundary location of replaced letters.

Figure 6. An example of a line of text showing how the left-2 condition may have occurred in various locations either within or adjacent to the fixated word. The arrow indicates the location of the center of the fixation.

Figure 7. Group median durations of fixations F1 following forward saccades for condition left-2 and the control condition, as a function of whether the boundary location was within or adjacent to the word being fixated.

Original
Text One of the few stories about a cat saving someone happened

Replacement
Text Zen ui hfn inx rhusbnr mluoh m vmh rmcbey ruanuen fmjjnent

Fix 1 One of the few stories about a cat saving someone happened

Fix 2 One of the inx rhusbnr mluoh m vmh rmcbey ruanuen fmjjnent

Fix 3 One of the few stories about a cat saving someone happened

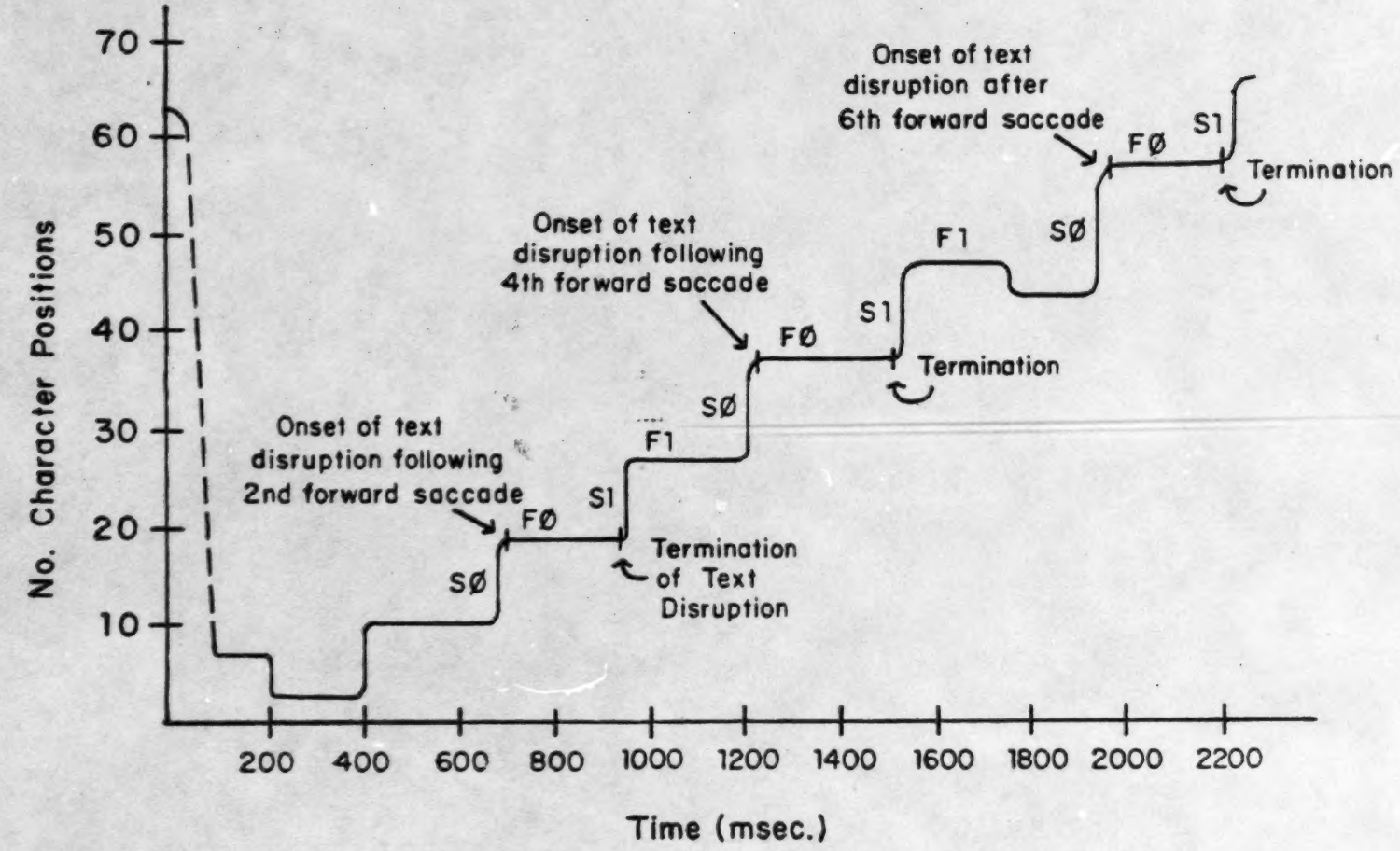
Fix 4 Zen ui hfn inx rhories about a cat saving someone happened

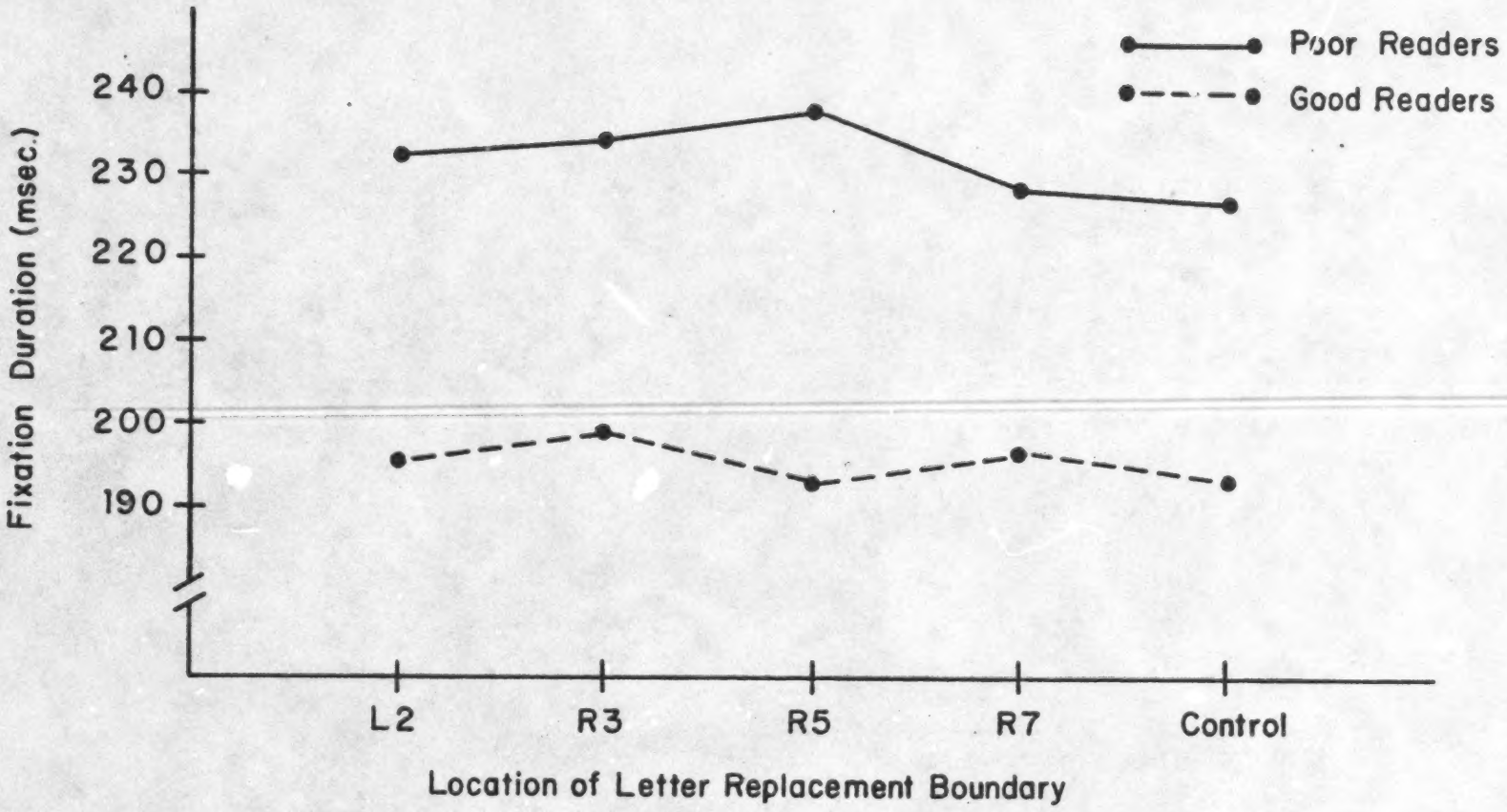
Fix 5 One of the few stories about a cat saving someone happened

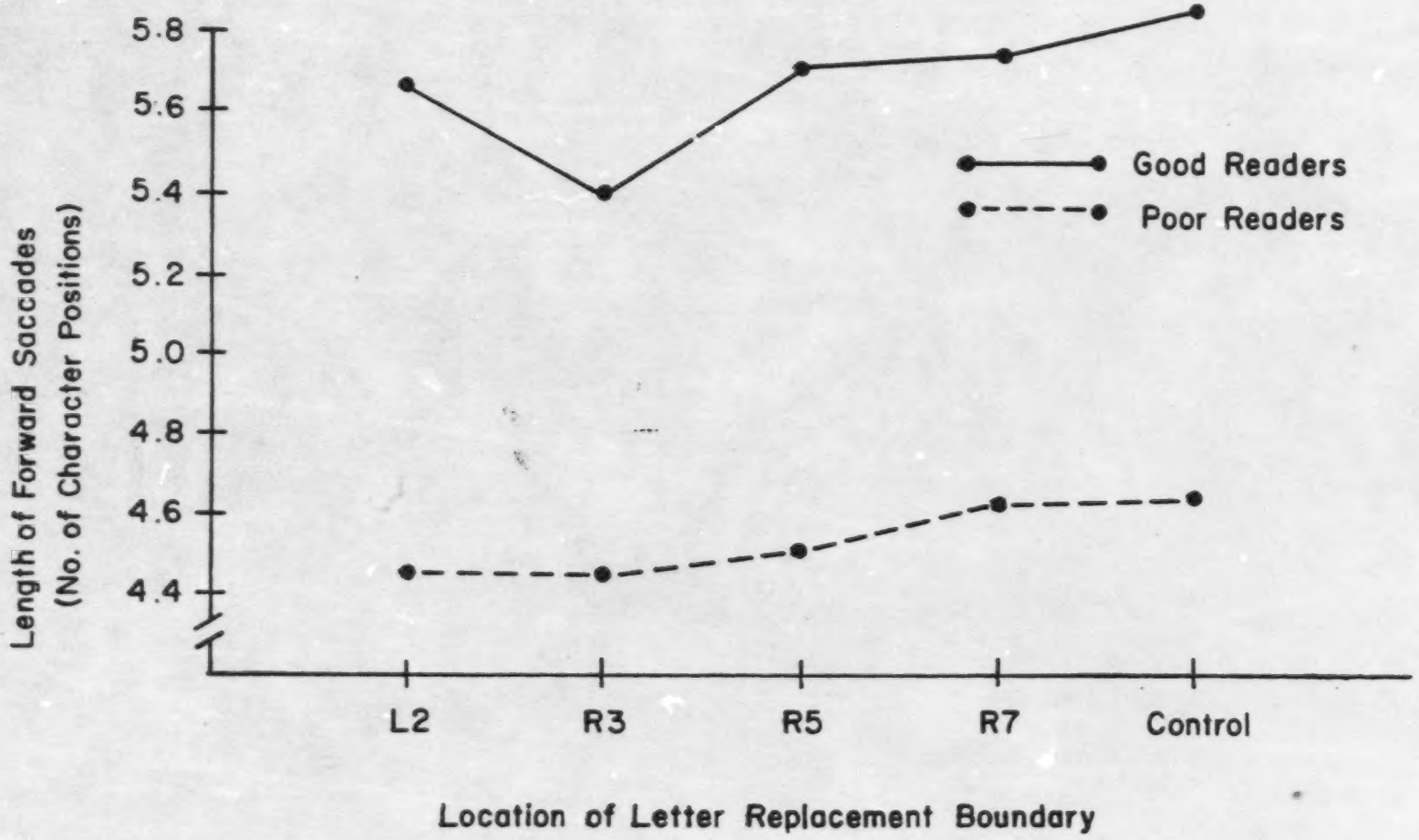
Fix 6 One of the few stories about a cat sacbey ruanuen fmjjnent

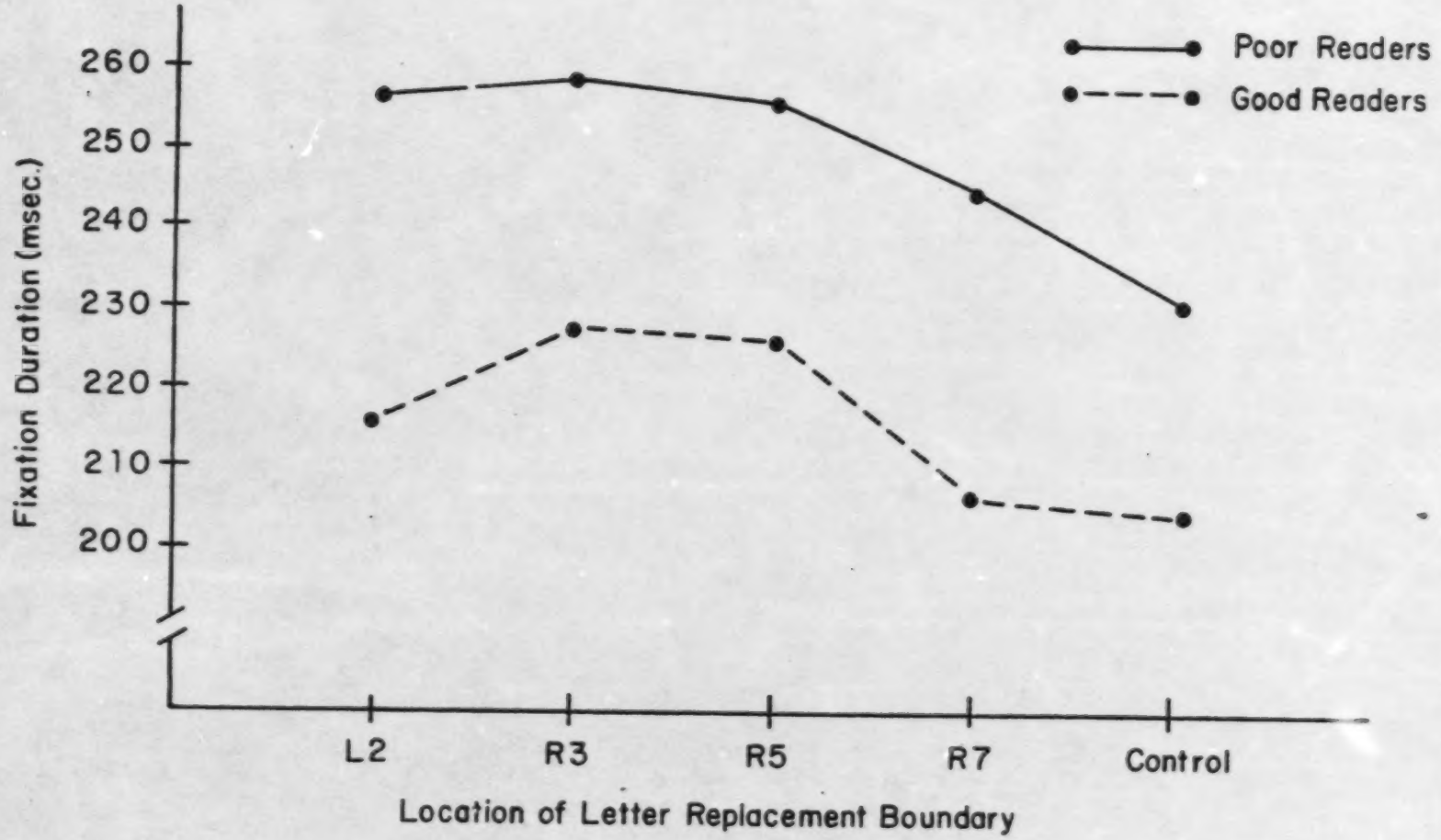
Fix 7 One of the few stories about a cat saving someone happened

Fix 8 One of the few stories about a cat saving someone happnent


No. Character Positions
70
60
50
40
30
20
10
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Time (msec.)
Onset of text disruption following 2nd forward saccade
SØ
FØ
S1
F1
Termination of Text Disruption
Onset of text disruption following 4th forward saccade
SØ
FØ
S1
F1
Termination
Onset of text disruption after 6th forward saccade
SØ
FØ
S1
Termination


Poor Readers
Good Readers
Fixation Duration (msec.)
240
230
220
210
200
190
L2
R3
R5
R7
Control
Location of Letter Replacement Boundary


5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
Length of Forward Saccades
(No. of Character Positions)
Good Readers
Poor Readers
L2
R3
R5
R7
Control
Location of Letter Replacement Boundary


Poor Readers
Good Readers
Fixation Duration (msec.)
260
250
240
230
220
210
200
L2
R3
R5
R7
Control
Location of Letter Replacement Boundary

Original Line

1. One of the few stories about a cat saving someone happened

Within-word Location

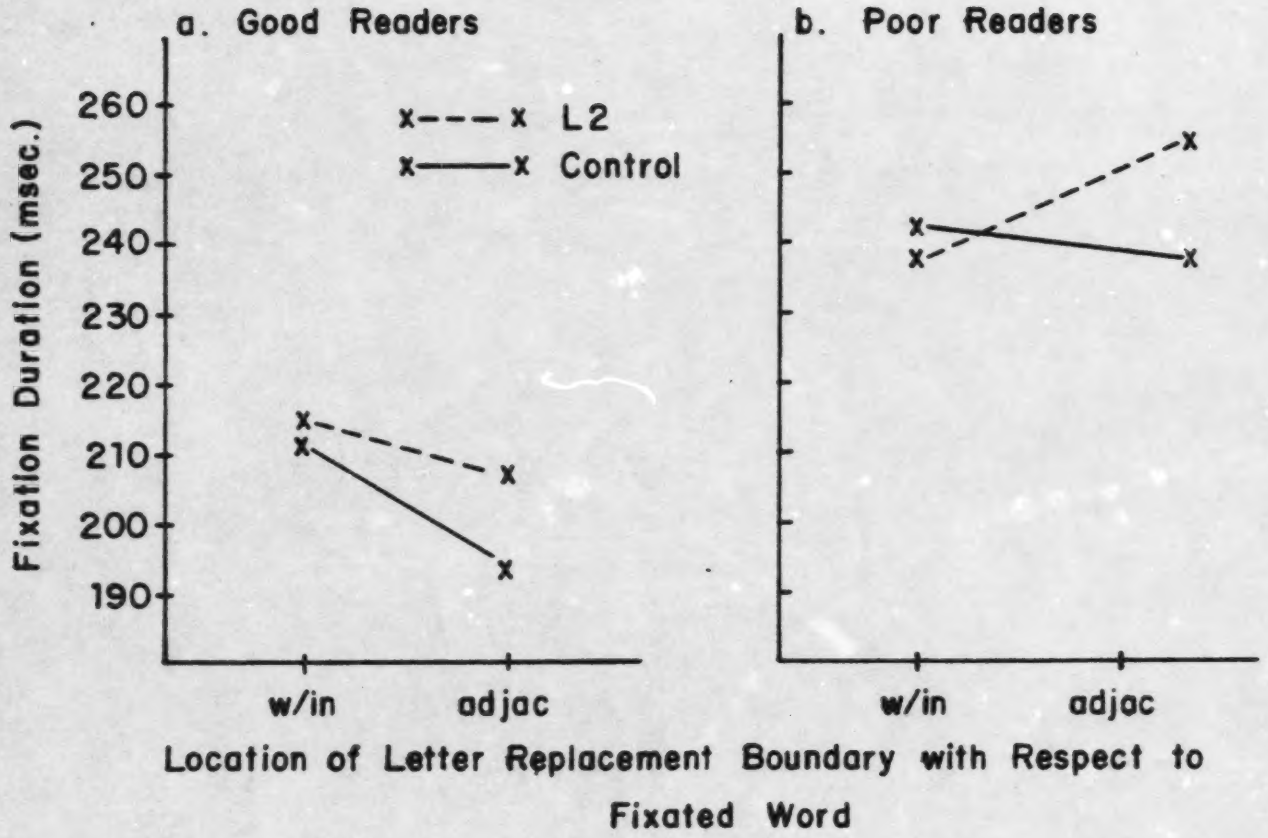
2. Zen ui hfn inx rhusbnr mlout a cat saving someone happened

Adjacent-word Location

3. Zen ui hfn inx rh usbnr mluoh a cat saving someone happened

4. Zen ui hfe few stories about a cat saving someone happened

5. Zen ui hfn inx stories about a cat saving someone happened


a. Good Readers
b. Poor Readers
x---x L2
x——x Control
Fixation Duration (msec.)
260
250
240
230
220
210
200
190
w/in
adjac
w/in
adjac
Location of Letter Replacement Boundary with Respect to Fixated Word

60